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ORIGINAL ARTICLE

An integrated anthracnose management approach in Tommy Atkins mango cultivars in Cundinamarca - Colombia

Juan Clímaco Hío[1,2*], Erika Martínez[1,2], Emerson Rojas[2], Jairo A. Osorio[2], Ginna Natalia Cruz[2], Alexander Bustos R[2]

Edited by
Angela Johana Espejo Mojica
editorus@javeriana.edu.co

1. Doctorado en Ciencias Naturales para el Desarrollo (Docinade) Universidad Nacional, Instituto Tecnológico de Costa Rica, Universidad Estatal a Distancia, Heredia, Costa Rica, CP 86-3000
2. Corporación Colombiana de Investigación Agropecuaria – AGROSAVIA, Km. 14 vía Mosquera – Bogotá, Mosquera, Colombia, CP 250047.

*jclimaco@agrosavia.co

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Abstract

Anthracnose, caused by *Colletotrichum gloeosporioides* in mango production, can lead to crop losses of 60 %. Synthetic fungicides constitute its leading management strategy. We evaluated combinations of different management practices to control anthracnose in a commercial Tommy Atkins mango grove in 2015 and 2016. We followed a randomized complete block experimental design with a subdivided plot arrangement composed of 12 treatments, three replicates per treatment, and one mango tree per replicate for 36 trees. Pruning was practiced at plot level (with and without pruning), nutrients were applied to subplots (soil fertilizer, foliar nutrient application, and no nutrient supply), and at sub-subplot level, three anthracnose management treatments were given (chemical, biological, and no treatment). In 2015 and 2016, the treatments involving natural or biological applications against anthracnose plus nutrient supply led to the most significant reductions in quiescent leaf infections and disease presence in flowers and fruits. In addition, pruning at specific crop development stages improved results. In light of our results, this integrated anthracnose management approach in mango production can deliver the expected results if implemented consistently.

Keywords: *Colletotrichum gloeosporioides*; biological pest control; chemical pest control; integrated pest; control; *Mangifera indica*.

1. Introduction

The fungal plant pathogen species complex *Colletotrichum gloeosporioides* (Penz.) Penz & Sacc causes the highly prevalent and destructive anthracnose disease in mango trees. Anthracnose mainly affects tree flowers and fruit development, leading to production losses ranging from 25 % to 60 % [1, 2, 3]. In 2019, Colombia experienced losses of approximately 261.154 tons of fresh and processed mango products to this disease [4] .

Mango farmers chiefly control anthracnose in their groves with synthetic pesticides, intensifying applications during flowering and heavy rainfall seasons, thus reducing disease incidence and severity by up to 55 %. Fungicides improve mango fruit physical quality, preventing disease-driven fruit blemishing. However, high chemical loads can accumulate in the harvested fruit, negatively affecting its commercialization (threatening consumer health) and the environment [5, 6, 7]. Reasonably, the chemical management of *C. gloeosporioides* should begin during early mango flowering stages to prevent costly fruit damage and flower and developing fruit losses that occur if the condition is not timely addressed [8].

Non-chemical anthracnose control alternatives have also been explored in mango crops. These include foliar plant extract applications on both crops and postharvest fruits [9], the use of yeasts and chlorine dioxide in postharvest treatments [10], and the application of ginger and cinnamon essential oils, which have shown positive effects in extending the fruit's shelf life and reducing anthracnose incidence [11]. A combination of chemical and biological alternatives and plant extracts can reduce anthracnose incidence to as low as 1 % in postharvest situations [12].

Complementary physical disease control strategies, such as immersing fruits in water at temperatures above 50 °C or steam treatment at 48 °C have led to a postharvest disease incidence decrease of 45 % to 52 % [13, 14, 15]. Additionally, mango treetop pruning has been found to reduce pest presence and increase flowering and yield by up to 26 % [16, 17].

All commercially grown mango varieties are equally susceptible to anthracnose. In cultures of the Tommy Atkins mango variety, of current growing commercial interest in Colombia, chemical applications for anthracnose control are conducted only at critical phenological stages, avoiding excessive use and residue of chemicals in harvested fruits and minimizing disease impact on crops through integrated control tools.

The integrated management of anthracnose in mango crops should involve early decision-making, implementing pruning and applying anthracnose control alternatives at the beginning of flowering, using chemical and biological methods, and incorporating natural extracts synergistically and complementarily. These practices would help farmers improve their current anthracnose control methods.

In this work we assessed alternative anthracnose management approaches, integrating a set of practices to reduce the incidence and severity of the pathogen while avoiding high use and frequency of chemicals. Specifically we aimed to evaluate the effects of different anthracnose control systems in the Tommy Atkins mango variety in the municipality of Tocaima, Cundinamarca, Colombia.

2. Materials and Methods

This study was conducted in a commercial mango grove of the Tommy Atkins variety located in Tocaima, Department of Cundinamarca, Colombia, between 2015 and 2016. The crop was situated at an elevation of 672 meters above sea level, with an average temperature of 27 °C and an annual rainfall of 1618 mm, providing suitable conditions for mango production [18].

Soil and leaf samples were collected and analyzed to assess the grove's initial conditions and design the experiment's nutrient application scheme. The experiment followed a randomized complete block design with split plots where the blocking factor was plot topography. The main plots were assigned to pruning treatments (with and without pruning), the subplots to the nutrient treatments (soil nutrients, foliar nutrients, and no nutrients), and the sub-subplots received different treatments for anthracnose control (chemical treatment, biological treatment, and no treatment). Twelve treatments were applied in this experiment, with three replicates and one mango tree as the experimental unit, resulting in 36 trees. Edge effects were considered when selecting trees to minimize bias and variability introduced by external environmental factors [19] (see **Table 1**).

Table 1. Treatments applied in 2015 and 2016 in mango grove of the Tommy Atkins variety to control anthracnose in the experimental plot.

Treatment	Pruning[1]	Nutrients[2]	Anthracnose Control mechanism[3]
T1	WP	WN	C1
T2	WP	WN	C2
T3	WP	WN	C0
T4	WP	NN	C1
T5	WP	NN	C2
T6	WP	NN	C0
T7	NP	WN	C1
T8	NP	WN	C2
T9	NP	WN	C0
T10	NP	NN	C1
T11	NP	NN	C2
T12	NP	NN	C0

[1] Pruning (WP: with pruning, NP: no pruning); [2] Nutrients (WN: with nutrients, NN: without nutrients); and [3] Anthracnose control mechanisms (C0: No anthracnose control, C1: anthracnose biological control, C2: anthracnose chemical control).

Main Plot - Pruning: For the main plot, maintenance pruning, and crown formation were conducted during the vegetative stage after the harvest. This involved removing unproductive branches, dry peduncles, and lower branches to enhance tree aeration and prevent moisture buildup.

Subplot - Nutrients: At subplot level, edaphic nutrients were applied during each production cycle when the soil reached field capacity. During the resting phase, a physical mixture containing nitrogen, phosphorus, potassium, calcium, and minor elements was applied to mango trees. Additionally, foliar nutrient applications were conducted following the recommendations in the literature, from bud emergence to fruit filling [20].

Sub-Subplot - Anthracnose control. The sub-subplot consisted of anthracnose treatments:

1. No anthracnose treatment (C0).
2. Commercial biological anthracnose treatment and plant extract products (C1) using a rotation of 98 % citrus extract (0.75 cc/L) during the tree's resting phase and during fruit development, *Purpureocillium lilacinus* (1 g/L) during the flowering phase, and *Bacillus subtilis* (5 cc/L) during fruit formation and growth.
3. Chemical anthracnose treatment (C2) using a rotation of the active ingredients Azoxystrobin (0.8 g/L) during the tree's resting phase and during the flowering phase, Propineb (2 g/L) during the pre-flowering and fruit development phases, and Captan (2.5 g/L) during fruit formation.

2.1. Monitoring leaf Quiescent Infections (QIs) and anthracnose in flowers and fruits:

To assess *C. gloeosporioides* quiescent infections (QIs) in leaves and anthracnose incidence in flowers and fruits, the following steps were followed:

1. Leaf Sampling: Twenty-five mature and healthy leaves were collected from the canopy of each tree to evaluate QIs in leaf tissue.

2. Surface Sterilization: The collected leaves were surface sterilized in the laboratory by immersing them in a 0.5 % sodium hypochlorite solution for 30 seconds.

3. Paraquat Treatment: After surface sterilization, the leaves were submerged in a 4 % paraquat solution for 90 minutes.

4. Humid Chambers: The treated leaves were then incubated in humid chambers at room temperature (18 $\pm$ 2 °C).

5. Incubation Period: After 12 days of incubation, the percentage of QIs in the leaves was determined. This was done using a modified diagrammatic colonization levels scale specifically designed for mango leaves [21].

6. Calculation of Area Under the Disease Progress Curve (AUDPC): The area under the disease progress curve (AUDPC) was calculated based on the percentage of QIs observed during the incubation period, keeping track of disease's progress and severity over time.

7. Anthracnose assessment in flowers and fruits: The percentage of affected panicles and fruits showing anthracnose symptoms was measured from the bud formation stage until harvest. Four points in the middle third of the outer part of each tree were selected for this evaluation, and for calculating the percentage of affected panicles and fruits with anthracnose symptoms, equation 1 was used.

$$\text{Percentage of incidence} = \frac{\text{Number of units affected}}{\text{Number of units sampled}} \times 100 \qquad (1)$$

8. To determine the percentage of latent infections (LI) in harvested fruits, 4 to 6 fruits per tree were selected and taken to the laboratory where they were washed and disinfected with 1 % NaClO for one minute, then placed in humid chambers at 20 °C until anthracnose symptoms appeared. Anthracnose incidence and severity in flowers and fruits were assessed using a diagrammatic scale as in [22], according to the characteristic symptoms of anthracnose caused by *C. gloeosporioides* [1, 23, 24].

We isolated fungi from latent Colletotrichum complex infections, performing taxonomic identification through morphological characters at culture and microscopic levels to ascertain the presence of *C. gloeosporioides*. Fungal pathogen identification agreed with previous studies by our own research group where the fungal cause of anthracnose in mango was also identified with molecular markers [23].

2.2. Statistical Analysis

To evaluate data normality assumptions, the Shapiro-Wilk test was used [22]. Homogeneity of variance was assessed using the Levene test [25], and the independence of errors was evaluated using the Durbin-Watson test [26].

Data from 2015 and 2016 were analyzed independently using generalized linear mixed models. The fixed part of the model corresponded to treatment, while the random part included blocks and trees as random factors. In cases where homoscedasticity assumptions were violated, heteroscedastic variance models were included. [27]

Different variance functions were used according to variable nature. Namely, the identity type variance function (varIdent) was used for the percentage of anthracnose in fruits (2015 - 2016); the exponential function (varExp) was used to model variables such as AUDPC (2015-2016), percentage of anthracnose (2015 - 2016), percentage of QIs in fruits and production; and the power variance function (varPower) was used for the variable percentage of anthracnose in fruits (2016).

The model selection process involved using information criteria such as Akaike (AIC) and Bayesian (BIC), as well as the maximum likelihood (logLik) values. These criteria were interpreted as measures of goodness of fit, and the model with the lowest value in each criterion was selected as the best variance model. This process helps find the most proper model for the data [28].

To compare means, the LSD Fisher test was used with a significance level of $p < 0.05$. Bonferroni corrections were applied to adjust for multiple comparisons. All the statistical analysis was performed using R statistical software, version 3.6.0.

3. Results and Discussion

3.1. Monitoring *C. gloeosporioides* Quiescent Infections (QIs) in leaves and anthracnose in flowers and fruits

In 2015, the treatments assessed for QIs in leaves showed significant differences in the area under the curve (AUDPC) values (F= 3.69, p=0.0498). Treatment T7 (NPWNC1) had the lowest AUDPC value (708.12), followed by treatments T8 (NPWNC2), T2 (WPWNC2), and T1 (WPWNC1) with AUDPC values of 776.58, 1,337.31, and 1,427.39, respectively. The treatments T3 (WPWNC0) and the absolute control had an average AUDPC value of 2,554. In 2016, there were also significant differences in AUDPC values among the assessed treatments (F=8.78, p=0.0027). Treatment T7 (WPWNC1) had the lowest AUDPC value (1,392.40), while treatment T6 (WPNNC0) had the highest AUDPC value (7,995.50) (**Table ??**).

In the second year of evaluation, treatments T7 (NPWNC1) and T1 (WPWNC1) showed the lowest presence of QIs in leaves, with AUDPC values of 1,392.40 and 3,487.70, respectively. These treatments, involving nutrient supply and the application of bio controllers in rotation, had a significantly different effect than treatments T6 (WPNNC0) and T12 (NPNNC0), which had AUDPC values of 7,995.50 and 5,619.17, respectively. Similar effects were seen in the first year of assessment, where treatments T8 (NPWNC2) and T7 (NPWNC1) were least affected by QIs, with AUDPC values 776.58 and 708.12, respectively. Treatment T3 (WPWNC0) and the absolute control (T12 NPNNC0) were the most affected by QIs, with AUDPC values of 2,921.46 and 2,187.43, respectively (Table 2).

As shown in Table 2, treatments T7 and T8 demonstrated the most significant IQ reductions over the two-year evaluation period. Both treatments incorporated nutrient supply and anthracnose control measures, with biological control proving particularly effective. Notably, neither treatment involved pruning. Treatment T10 also exhibited lower IQ levels in both years, primarily due to the successful application of biological anthracnose control. However, pruning, nutrient supply, and anthracnose control treatments (T1 and T2) also exhibited some disease reduction. This overall improvement is likely attributable to the fact that treated trees originated from a previously neglected, implemented, and evaluated orchard.

Table 2. Area under the curve of *C. gloeosporioides* Quiescent Infections (QIs) in experimental Tommy Atkins mango tree leaves in 2015 and 2016.

Treatment	AUDPC 2015	SD 2015	Test LSD-Fisher 2015	AUDPC 2016	SD 2016	Test LSD-Fisher 2016
WPWNC0 T3	2921.46	246.87	a	5507.33	304.82	cd
WPWNC1 T1	1427.39	173.15	cd	3487.70	152.39	f
WPWNC2 T2	1337.31	184.80	cd	5232.00	260.89	de
WPNNC0 T6	1882.27	170.97	b	7995.50	304.82	a
WPNNC1 T4	1792.62	204.74	bc	4848.17	152.39	e
WPNNC2 T5	2443.68	360.43	ab	6532.33	260.89	b
NPWNC0 T9	1965.59	175.90	b	6046.50	304.82	bc
NPWNC1 T7	708.12	131.51	e	1392.40	152.39	h
NPWNC2 T8	776.58	168.46	e	2230.40	260.89	g
NPNNC0 T12	2187.43	189.49	b	5619.17	304.82	cd
NPNNC1 T10	1264.77	161.93	d	1840.23	152.39	g
NPNNC2 T11	1791.00	211.34	bc	3668.80	260.89	f

Summary of the interactions of repeated measures from ANOVA and Fisher's LSD test between treatments in the two consecutive years. Different letters indicate significant differences at $p < 0.05$. WP: With pruning, NP: Without pruning, WN: with nutrients, NN: without nutrients, C0: without control, C1: biological control, and C2 extract: Chemical control.

A consistent management plan should be deployed to assess the impact of pruning. Several studies emphasize the importance of implementing management practices, such as pruning, nutrient supply, and targeted anthracnose control, to minimize disease incidence in various crops [29].

Anthracnose presence in mango flowers of the Tommy Atkins variety was evaluated, with the following results. In 2015, the interaction between pruning, nutrient supply, and anthracnose control type significantly influenced disease severity in flowers ($F=6.24$, $p=0.0107$). In treatments T3 (NPWNC0) and T8 (NPWNC2), flowers were the least affected by the disease, 27.67 % and 29.34 %, respectively, whereas treatments T10 (NPNNC1) and T12 (NPNNC0), had the highest flower disease values at 60.49 % and 53.36 %, respectively. Although T3 had the highest value of IQs in leaves, it had the opposite effect on flowers, and T8 effectively reduced IQs in leaves and anthracnose in flowers, highlighting the role of nutrient supply, a common factor to both treatments, in these outcomes. Treatment T10 reduced IQs but did not reduce disease in flowers, confirming that nutrient supply is an important factor in preventing losses.

The results indicate that nutrient supply, guided by soil and leaf tissue analysis, effectively reduced anthracnose in flowers in treatments T3 and T8, regardless of pruning status. However, this trend was not correlated with the percentage of IQs in leaves in these treatments, as they revealed the opposite outcomes. Treatments T9 and T12 displayed a higher incidence of IQs compared to anthracnose incidence levels in flowers in 2015. Treatment T7 was particularly effective in reducing IQs on leaves and demonstrated efficacy in controlling anthracnose in flowers. Conversely, T10, one of the top treatments for reducing IQs, was less successful in controlling anthracnose on flowers.

In 2016, the presence of anthracnose in flowers was also significantly modulated by the interaction between pruning and anthracnose control type (F=0.27, p=0.7702). The best treatments in terms of disease reduction were T1 (WPWNC1), with a disease incidence of 3.28 %, followed by T2 (WPWNC2), with 6.97 %, and T3 (WPWNC0), with 8.42 %. These results indicate that nutrient supply and pruning in the second year of evaluation positively reduced anthracnose in flowers. Comparing the results of T1 (WPWNC1) with the highest infection percentages seen in treatments T9 (NPWNC0) and T12 (NPNNC0) at 34.36 % and 26.67 %, respectively, the reduction in disease severity was 90.5 % and 87.7 %, respectively (**Fig. 1**).

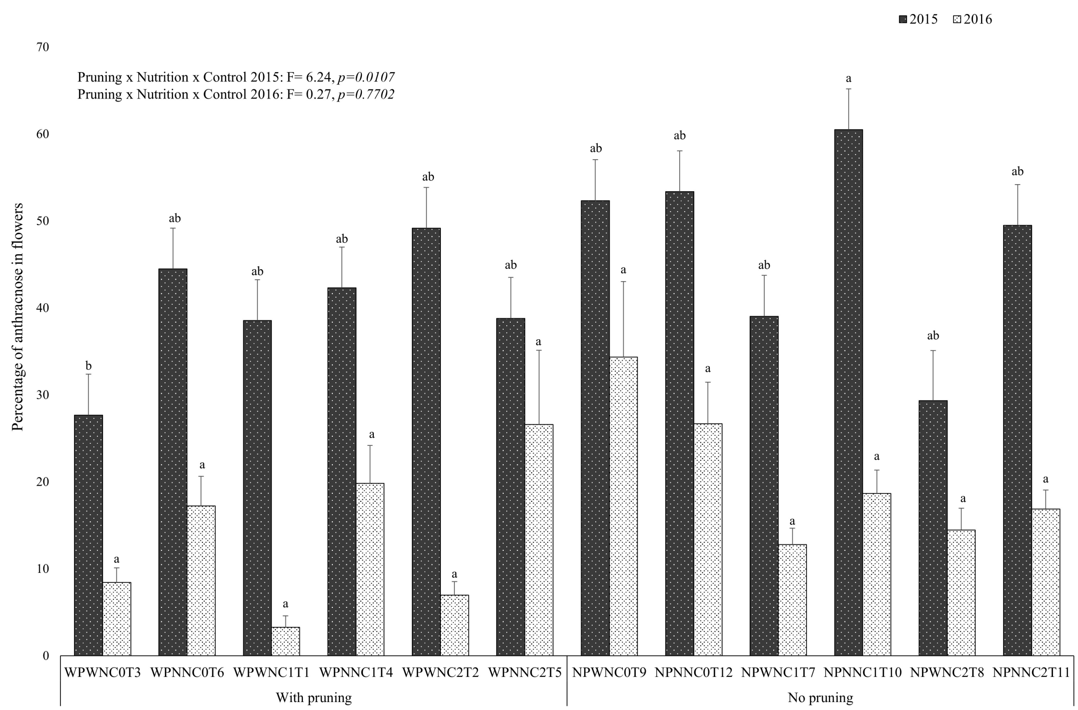

Figure 1. Anthracnose incidence (%) in Tommy Atkins mango flowers in 2015 and 2016, a summary of the interactions of repeated measures ANOVA and Fisher's LSD test between treatments in 2015 and 2016. Different letters show significant differences at p <0.05, with ± 95 % confidence. WN: with nutrient application, NN: without nutrient application, C0: without control, C1: biological control, C2: chemical control.

These findings suggest that proper nutrient supply and pruning practices can significantly reduce anthracnose severity in Tommy Atkins mango flowers. Treatment T3 (NPWNC0) in 2015 and treatment T1 (WPWNC1) in 2016 were the most effective in controlling the disease, highlighting the importance of implementing integrated management strategies for anthracnose in mango crops.

Our results align with findings from other studies on avocado and mango crops. In avocado cultivars, implementing practices such as pruning, crown management, and removing diseased fruit, branches, and peduncles reduced anthracnose source inocula and mitigated disease impact [30, 24].

Fungicide use has been a widely studied and applied approach to control anthracnose in mango groves and other fruit trees. Active ingredients such as propiconazole, difenoconazole, carbendazim, benomyl, maneb, and captan have traditionally controlled the disease. However, indiscriminate and inadequate use of fungicides can lead to pathogen resistance, compromising fruit safety, increasing production costs, and negatively impacting human and animal health and the environment [31, 29].

Research has shown that alternating and combining synthetic and non-synthetic means for disease control is central to preventing pathogen resistance. Studies have shown up to a 92 % reduction in anthracnose in mango crops by rotating fungicides based on tebuconazole and trifloxystrobin, and alternating products like metiram and pyraclostrobin reduced the disease by 89 %. On the other hand, fungicides such as methyl thiophanate, difenoconazole, and carbendazim had lower efficacy, reducing the disease by only 25 %. Combining chemical control with alternative strategies is recommended to mitigate environmental impacts and prevent pathogen resistance [32, 33].

Regarding the presence of anthracnose in fruits in formation, in 2015, we observed significant differences in the interaction among pruning, nutrient supply, and anthracnose control ($F = 6.86$, $P = 0.0013$). T7 (NPWNC1) was the treatment with the lowest disease incidence on fruits (21.76%), followed by T1 (WPWNC1) and T2 (WPWNC2), with incidences of 22.77 % and 23.02 %, respectively. In contrast, the treatments with the highest fruit disease levels were T9 (NPWNC0): 48 % and T10 (NPNNC1): 51.48%. In 2016, the interaction between pruning, nutrient supply, and anthracnose control was not significant ($F = 1.24$, $p = 0.293$). Treatments T2 (WPWNC2), T1 (WPWNC1), and T5 (WPNNC2) had the lowest fruit anthracnose incidences (3.3 %, 4.78 % and 8.66 % respectively), while the treatments with the highest disease incidences in fruits were T6 (WPNNC0) and T3 (WPWNC0), with values of 32.54 % and 32.25 %, respectively (**Fig. 2**).

The results obtained in fruits showed that the largest affectation seen in the first year compared to the second year is likely due to implementing practices in conjunction with control products within an integrated management scheme. The benefits of nutrient supply and pruning are reflected in established crops from the second year onwards for most perennial crops, including mango, avocado, and citrus, among others, considering that pruning and nutrition allow for improved productivity, yield, and fruit quality as long as they are implemented [36]. However, the research also highlights the efficacy of biological control agents, indicating that they can effectively reduce disease incidence in mango fruits.

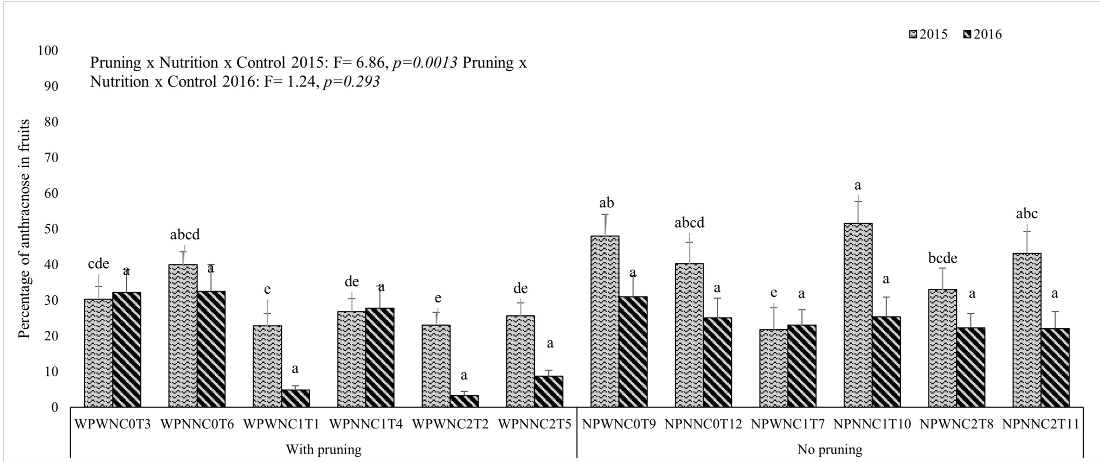

Figure 2. Incidence of anthracnose (%) in fruits in 2015 and 2016, a summary of the interactions of repeated measures ANOVA and Fisher's LSD test between treatments in 2015 and 2016. Different letters mark significant differences at p <0.05, with ±95 % confidence. *WN: with nutrient supply, NN: without nutrient supply, C0: without anthracnose control, C1: biological anthracnose control, C2: chemical anthracnose control.

Studies have revealed that proper nutrient management, providing essential elements like potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), boron (B), manganese (Mn), zinc (Zn), silicon (Si), nickel (Ni), and molybdenum (Mo), can contribute to reducing disease in mango trees. Specifically, organic or synthetic fertilizers can improve plant health and decrease overall disease incidence and sudden death caused by pathogens like *Ceratocystis* sp. and *Ophiostoma* sp. [32].

Furthermore, in mango crops of the Kent and Tommy varieties, applying fertilizers during their different physiological stages positively influences the yields and quality of harvested fruits, decreasing forming fruit drop and raising overall production [33]. In mango production, adequate water supply is essential for nutrient absorption, transport, metabolism, photosynthesis, thermal regulation, and overall tree physiological processes, favoring production stability and quality [34].

Regarding the percentage of quiescent infections (QIs) in harvested Tommy Atkins mango fruits, we only obtained results in 2016 (since there was no rainfall and fruits were absent in 2015) revealing significant differences in the interaction of pruning, nutrient supply, and disease control type (F= 4,51 P=0,0279). Treatments T5 (WPNNC2) and T2 (WPWNC2) revealed less affected fruits at 3.41 % and 3.96 %, respectively, compared to treatment T12 (NPNNC0), which had a disease incidence of 11.59 %. These findings suggest that the combined practices of pruning and nutrient supply, applied in rotation, can significantly reduce the occurrence of QIs in harvested mango fruits (**Fig. 3**). The combination of techniques, such as chemical, biological, and physical control, and inherent resistance, coupled with preventive actions like field fungicide application and post-harvest treatments, are the most effective ways to prevent and treat anthracnose [35, 1].

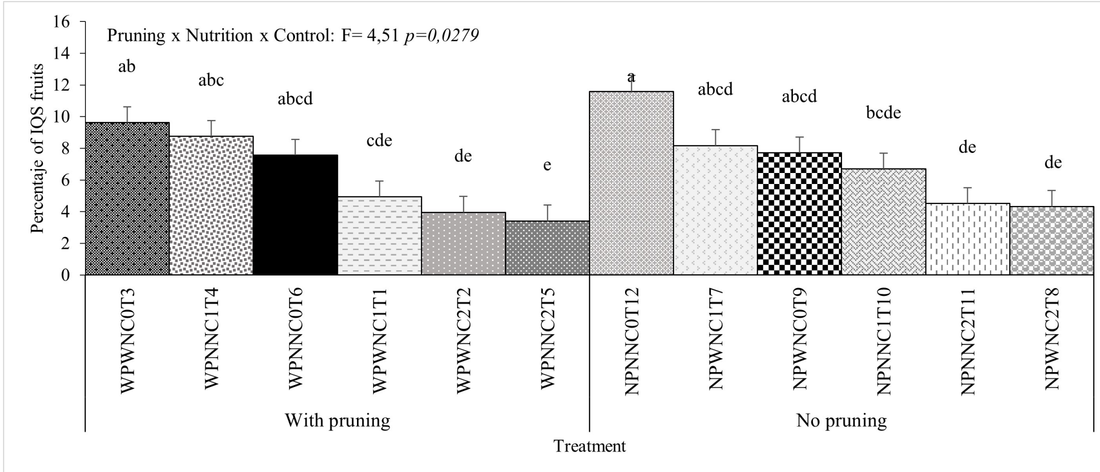

Figure 3. Percentage of anthracnose quiescent infections (QIs) in mango fruits harvested in 2016, providing a summary of the interactions of repeated measures ANOVA and Fischer 2016 LSD test. Different letters show significant differences at $p < 0.05$, with ± 95 % confidence. *WN: with nutrient supply, NN: without nutrient supply, C0: without anthracnose control, C1: biological anthracnose control, C2: chemical anthracnose control.

Lacking fruits in 2015, we were unable to determine their IQ status. In 2016 IQs had lower incidence and severity in flowers and forming fruits. The harvested fruit from the treatments involving biological disease control and plant extracts showed the lowest percentages of IQs, particularly under pruning and nutrient supply, which become tangible in established crops from the second year onwards for most perennial crops, including mango, avocado, and citrus, considering that pruning and nutrition allow for improved productivity, yield, and fruit quality as long as they are implemented [36].

Moreover, evidence also highlights the efficacy of biological control agents, indicating that they can effectively reduce disease incidence in mango fruits. Biological plant disease control technologies involving beneficial microorganisms have gained recent recognition due to their effectiveness in minimizing diseases in leaves, flowers, and fruits. Implementing these practices within an integrated management scheme enhances disease control and promotes harvested fruit safety. One of the significant advantages of using biological products is their minimal impact on the environment and crop-associated biodiversity. Reducing reliance on chemical synthesis products can minimize harmful environmental effects, leading to a more sustainable and eco-friendly production system [37].

Research has shown the effectiveness of microorganisms in controlling *Colletotrichum* spp., the causal agent of anthracnose, in various fruit trees, including apple, papaya, avocado, and mango. Bacteria of the genera *Bacillus*, *Trichoderma*, and *Streptomyces* have shown great promise among the tested microorganisms. These microorganisms possess different mechanisms of action, such as the production of antimicrobial compounds, lytic enzymes, antibiosis, bioactive secondary metabolites, deactivation of pathogen enzymes, and mycoparasitism, among others [3].

Trichoderma asperellum shows promising results as an alternative for controlling anthracnose in mangoes. In vitro tests have shown its inhibitory effects on *Colletotrichum gloeosporioides*' growth, the causal agent of anthracnose, with a control rate of 91 % [38]. Similarly, other Trichoderma species like *T. harzianum*, *T. asperellum*, and *T. longibrachiatum* have also shown inhibitory effects on *C. gloeosporioides* in vitro assays, with inhibition rates ranging from 9.5 % to 22.5 % [39].

Additionally, *Bacillus subtilis* subsp. *spizizenii* produces volatile organic compounds (VOCs) that inhibit Colletotrichum sp. mycelial growth by 60 % under laboratory conditions [40]. Similarly, strains of *Bacillus licheniformis* M2-7 and *B. licheniformis* LYA12 have shown inhibitory effects on *Colletotrichum* sp., causing hyphal fragmentation with intracellular inclusion bodies, swellings, and malformations, resulting in a 40 % growth reduction [41].

Similarly, microorganisms and plant extracts have also shown promise in controlling anthracnose. Studies have proven the effectiveness of extracts containing ascorbic acid and phenolic compounds (including phenolic acids, esters, and flavonols), particularly catechin, in controlling anthracnose and powdery mildew. Combining preventive management practices, considering the phenology of the crop, physiological stress stages (flowering, fruit formation, and pre-harvest), and periods of significant rainfall can enhance the effectiveness of plant extracts [42]. For instance, lemon peel extract (LPE) at concentrations of 1.75 to 2.5 g/L completely controls the growth and development of *C. gloeosporioides*, distorting mycelia, swelling of conidia, and cytoplasmic discharge. The Minimum Effective Concentration (MEC) of LPE in vivo was determined as 1.75 g/L, indicating its potential as a protective, simultaneous, and curative treatment to inhibit and decrease anthracnose infection in mango fruits [43].

These results align with earlier studies showing how diverse biological control agents and plant extracts effectively diminish latent infections and manage fruit pathogens during postharvest scenarios. For instance, *Paecilomyces* spp., *Bacillus* spp., and citrus seed extract can decrease the expression of quiescent infections and inhibit the growth of *C. gloeosporioides* in laboratory studies [19].

In postharvest applications, plant extracts in combination with biocontrol microorganisms like *Rodhotorula minuta*, *Bacillus subtilis*, and Trichoderma spp. were effective against fruit pathogens such as *Colletotrichum* sp., *Lasiodiplodia* spp., and powdery mildew [44, 45, 46, 47]. These approaches aim to achieve fruit without chemical residues, promoting environmental sustainability and preserving beneficial fauna associated with crops; biological control and its agricultural applications have reduced effects on the environment and hinder adverse effects on human and animal health [48].

In addition to biological control, postharvest techniques have been employed to manage anthracnose and quiescent infections. Hot air, hydrothermal treatments, and modified atmospheres can reduce the impact of quiescent infections during fruit storage [49]. Other techniques, such as ultraviolet light and ozone, have also been explored [50, 51].

A combination of hydrothermal treatment at 53 °C for 5 minutes, chitin addition at 10 mg L-1, and subsequent tempering of mangoes in suspensions of *Rhodotorula glutinis* Lv316 or *Lysinibacillus xylaniticus* Ap282 has shown efficacies of 83 % to 89 % in controlling anthracnose originating from quiescent infections of *C. gloeosporioides* in mango fruits of the Sugar variety [14]. These outcomes demonstrate the potential of integrated approaches and postharvest techniques in effectively managing anthracnose and reducing quiescent infections in mango fruits [1].

Finally, the analysis of the overall response to anthracnose treatments showed that treatments T7, T8, and T1 mainly included applying biological controls and plant extracts together with soil nutrient supply and pruning only in T1. In contrast, treatments T6 and T5, which included anthracnose treatments without pruning or nutrient supply, showed higher levels of disease in the plant organs evaluated, confirming that nutrient supply, complemented by anthracnose control, is fundamental to the effective disease management and the reduction of IQs in leaves. Furthermore, in our study pruning did not show a direct relationship with disease reduction, possibly because it was not previously used in management. This study should be continued to assess the long-term positive effect of pruning within integrated management.

4. Conclusions

Our findings underscore the importance of implementing an integrated approach to anthracnose management in mango production, combining cultivation practices, proper nutrient supply, irrigation, and applications of chemical or biological products. The integration of these strategies can reduce disease incidence and improve mango trees' overall health and productivity.

We tested different alternative systems to manage anthracnose in mango crops under tropical conditions, with positive results from all disease management treatments. Thus, we would like to suggest implementing biological or natural control alternatives as a first-line control strategy integrated with nutrient supply and canopy management, leaving chemical control as the last option.

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6. Conflict of interest

The authors declared no potential conflicts of interest concerning the research, authorship, and publication of this article.

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Enfoque integrado para el manejo de la antracnosis en cultivos de mango Tommy Atkins en Cundinamarca - Colombia

Resumen: La antracnosis, causada por *Colletotrichum gloeosporioides*, puede ocasionar pérdidas de hasta 60 % en los cultivos en la producción de mango. Los fungicidas sintéticos constituyen su principal estrategia de manejo. En este estudio, evaluamos combinaciones de diferentes prácticas de manejo para controlar la antracnosis en un huerto comercial de mango Tommy Atkins en 2015 y 2016. Aplicamos un diseño experimental de bloques completos al azar con un arreglo de parcelas subdivididas, compuesto por 12 tratamientos, tres réplicas por tratamiento y un árbol de mango por réplica, para un total de 36 árboles. Realizamos poda a nivel de parcela (con y sin poda) y aplicamos nutrientes a las subparcelas (fertilizante en el suelo, aplicación foliar de nutrientes y sin aplicación de nutrientes), también aplicamos tres tratamientos para el manejo de la antracnosis (químico, biológico y sin tratamiento) a nivel de subparcela. En 2015 y 2016, los tratamientos que incluyeron aplicaciones naturales o biológicas contra la antracnosis, junto con el suministro de nutrientes condujeron a mayor reducción de infecciones latentes en hojas y menor presencia de la enfermedad en flores y frutos. Además, la poda en etapas específicas del desarrollo del cultivo mejoró los resultados. A la luz de nuestros resultados, este enfoque integrado para el manejo de la antracnosis en la producción de mango puede ofrecer los resultados esperados si se implementa de manera consistente.

Palabras Clave: *Colletotrichum gloeosporioides*; control biológico de plagas; control químico de plagas; manejo integrado de plagas; *Mangifera indica*.

Abordagem integrada para o manejo da antracnose em cultivos de manga Tommy Atkins em Cundinamarca - Colômbia

Resumo: A antracnose, causada por *Colletotrichum gloeosporioides*, pode ocasionar perdas de até 60 % nas plantações de manga. Os fungicidas sintéticos constituem a principal estratégia de manejo. Neste estudo, avaliamos combinações de diferentes práticas de manejo para controlar a antracnose em um pomar comercial de manga Tommy Atkins em 2015 e 2016. Aplicamos um delineamento experimental de blocos completos casualizados com um arranjo de parcelas subdivididas, composto por 12 tratamentos, três réplicas por tratamento e uma árvore de manga por réplica, totalizando 36 árvores. Realizamos poda a nível de parcela (com e sem poda) e aplicamos nutrientes nas subparcelas (fertilizante no solo, aplicação foliar de nutrientes e sem aplicação de nutrientes), além de três tratamentos para o manejo da antracnose (químico, biológico e sem tratamento) a nível de subparcela. Em 2015 e 2016, os tratamentos que incluíram aplicações naturais ou biológicas contra a antracnose, junto com o fornecimento de nutrientes, resultaram nas maiores reduções de infecções latentes nas folhas e na menor presença da doença em flores e frutos. Além disso, a poda em estágios específicos do desenvolvimento da cultura melhorou os resultados. À luz de nossos resultados, uma abordagem integrada para o manejo da antracnose na produção de manga pode gerar os resultados esperados se implementada de maneira consistente.egridade do habitat, tornando-se assim um indicador confiável do estado de conservação do mesmo.

Palavras-chave: *Colletotrichum gloeosporioides*; controle biológico de pragas; controle químico de pragas; manejo integrado de pragas; *Mangifera indica*.

Juan Climaco Hio

Agronomic Engineer, Agricultural Administrator, Master in Applied Biology, Specialist in plant parasitic nematodes, Master Researcher in Phytopathology with experience in pathogen biology, epidemiology, management and control of plant diseases. Ph.D. student in Ciencias Naturales para el Desarrollo (DOCINADE), Instituto Tecnológico de Costa Rica, Universidad Nacional, Universidad Estatal a Distancia, Costa Rica. 30 years of experience in the Corporación Colombiana de Investigación Agropecuaria (Agrosavia).

ORCID: 0000-0003-3620-4569

Erika Patricia Martínez Lemus

Master Researcher in plant pathology with emphasis on epidemiology and disease management at Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA), Ph.D. student in Ciencias Naturales para el de Desarrollo (DOCINADE), Instituto Tecnológico de Costa Rica, Universidad Nacional, Universidad Estatal a Distancia, Costa Rica. Experience in research projects on the distribution, spread and identification of predisposing factors of diseases for the generation of preventive management strategies.

ORCID: 0000-0002-5580-1564

Henry Alexander Bustos Rodríguez

Leader of research projects and technology transfer in agricultural systems at the national level, with international cooperation in Latin America and Europe. Interested in Integrated Pest and Disease Management in agricultural systems, with an emphasis on biological control, mass rearing of natural enemies, crop pollination, and ecosystem modeling.

ORCID: 0000-0002-2432-5702

Emerson Duvan Rojas Zambrano

Agronomic engineer with skills in seedbed management, integrated soil management, fertilization plans and agronomic management of vegetables and fruit trees. Experienced in phytosanitary research, focusing on integrated disease management in some production systems such as Passion Fruit, Cape Gooseberry and Mango. Currently a professional researcher at the Corporación Colombiana de Investigación Agropecuaria (Agrosavia)

ORCID: 0000-0001-7605-3457

Ginna Natalia Cruz Castiblanco

Agronomic Engineer, Specialist and Master in Applied Statistics, with eleven years of experience in research and modeling of complex data in various areas of the agricultural sector. My research focuses on agricultural epidemiology and the use of Bayesian statistical methods, experimental design, sampling, and Machine Learning applied to information analysis in different productive systems

ORCID: 0000-0003-2355-4914

Jairo Antonio Osorio Cardona

Agronomic Engineer with a Master's and Ph.D. in Plant Pathology, has been dedicated to researching epidemiological aspects and disease control of fruit crops in Colombia for over three decades. His work has primarily focused on investigating the sources of inoculum for pathogens causing diseases like anthracnose in citrus, tomato, tree tomato, soursop, mango, and others. Through this research, he has developed preventive strategies to mitigate the impact of these diseases on fruit production and quality. Additionally, he has conducted in-depth studies on root rot in passionflowers, examining the infection mechanisms and the influence of soil physical and chemical factors on disease occurrence.

ORCID: 0000-0002-3700-7738